Recovery of Nutrients from Source-Separated Urine via Biochar Sorption

Creating Marketable Products from Human Waste

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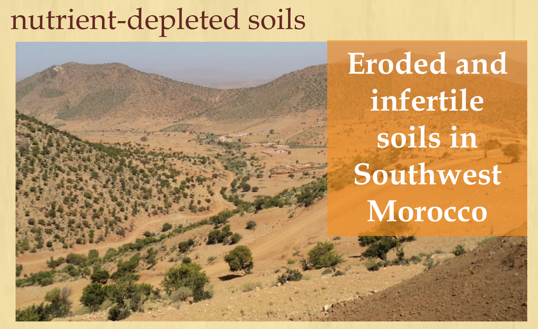
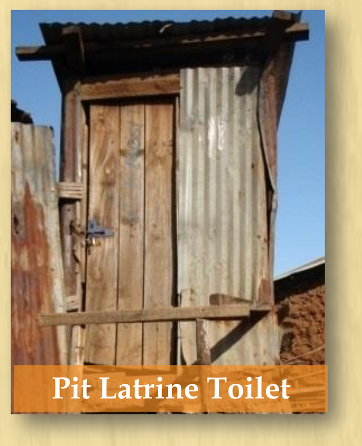
The Problem

- 2.5 billion people (~40% of global population) lack access to basic sanitation, with about 1.1 billion people still defecating in the open[1]
- Diarrhea kills more than 1.5 million people each year[1]
- Conventional wastewater treatment views nitrogen and phosphorus as pollutants
- Much of the world relies on agriculture for livelihoods but reside in areas with eroded and nutrient-depleted soils



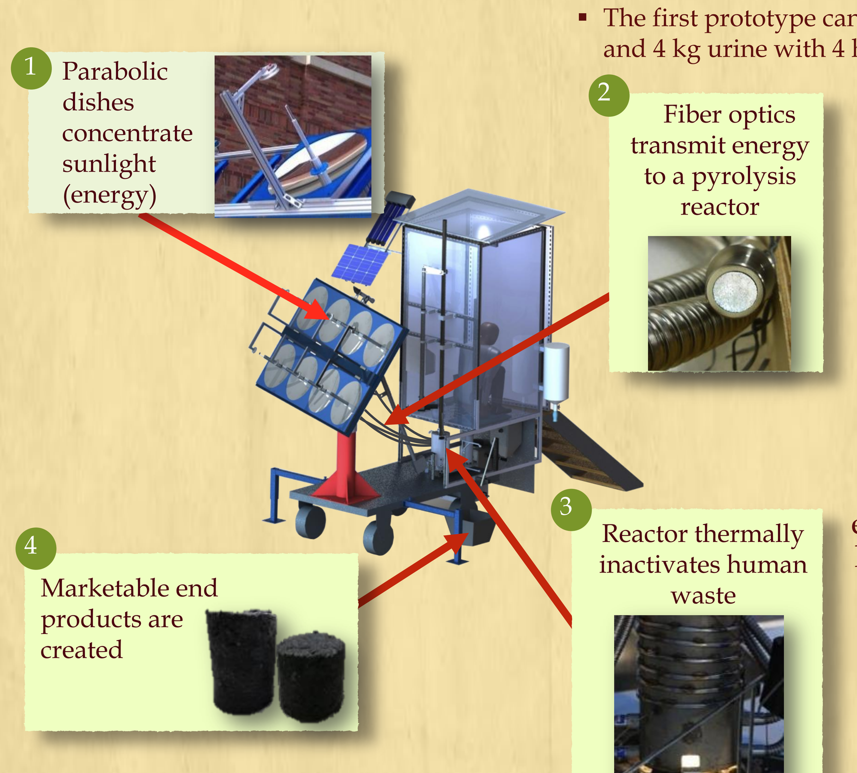
Eroded and infertile soils in Southwest Morocco



Pit Latrine Toilet

The Sol-Char Solution:

- The first prototype can process 2 kg feces and 4 kg urine with 4 hours of sunshine



The Sol-Char Toilet creates usable products without grid energy, water, or sewage infrastructure by harnessing solar energy to power a high-temperature reactor that converts human waste to biochar.

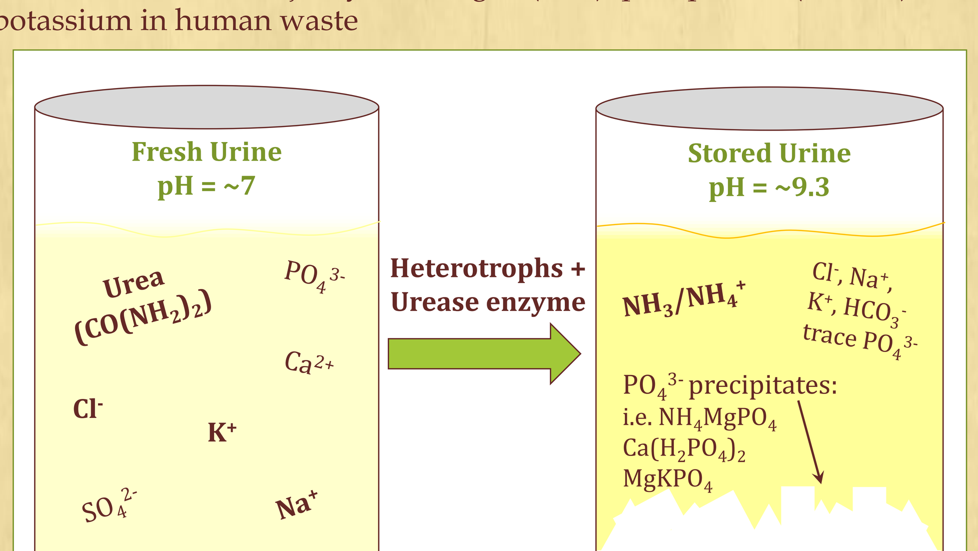
Biochar as a Useful Product

Biochar made by the carbonization of biomass has many desirable properties:

Property	Function
Surface area / Microporosity	Accumulation of organic material, biofilm establishment, sorption, retention of inputs and H_2O
Cation Exchange Capacity (CEC)	Retention and bioavailability of inputs (e.g. N, P, and K fertilizers)
pH/liming effect	pH balance and buffering
Longevity in soils	CO_2 sequestration, long-lasting benefits
Energy Content	Potential for clean-burning fuel
Relevant fertilizer properties	
Nutrient Content	Bioavailability of nutrients in product
Environmental hazards	Heavy metals and pathogens

Urine Chemistry

- Urine contains the majority of nitrogen (90%), phosphorus (25-75%) and potassium in human waste



Experimental Design

Research Goals

- Determine adsorptive capacity of various biochars for nitrogen from human urine
- Determine possible sorption mechanisms
- Asses viability of nutrient-loaded biochar as a fertilizer

Biochar Preparation

- Feces from anonymous donors in ceramic crucibles
- Wood feedstocks gathered from various sources and cut into small pieces
- Materials charred in a furnace and kept at desired temperature for 2 hours
- Biochar is finely ground and sieved to pass No. 100 (0.152mm)

Urine Preparation

Synthetic Urine
Prepared based on recipe from EAWAG[3]

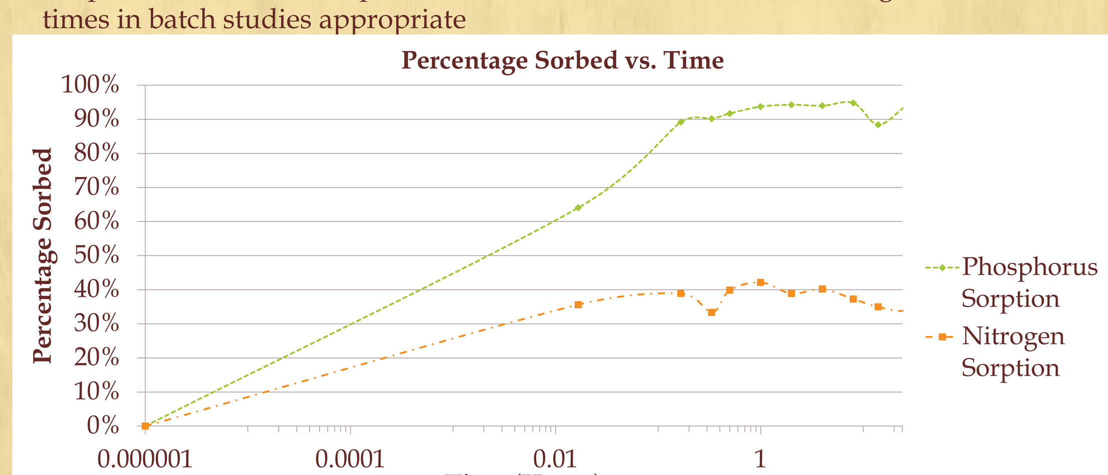
Urine Type	NH_3-N (mg/L)	PO_4-P (mg/L)
Fresh	125-250	357-605
Stored	2600-4200	154-250
Synthetic	3700-8060	1365-1555

Real Urine

- Collected from anonymous donors and mixed in 1 liter bottles
- Urine was kept at 37°C with 50 mg/L urease enzyme to ensure full hydrolysis – TKN and NH_3 analysis conducted to confirm
- In general, $[NH_3/NH_4^+]$ in synthetic urine was higher than real urine (~2X), which is one possible reason for higher uptake for synthetic urine

Kinetic Batch Studies

- Prepared urine+biochar mixtures in batches to be mixed for various times
- All possible ammonia sorption occurred within a few hours, making 24 hour reaction times in batch studies appropriate



Batch Sorption Studies

1. Urine pre-filtered to remove any suspended precipitates formed during hydrolysis
2. 10mL of liquid urine sample is combined with 2-8g biochar
3. Biochar–urine slurry samples are placed in a tumbler for 24 hours
4. Samples are removed and vacuum-filtered through a GF-C filter
5. pH, total NH_3 and phosphorus are tested using HACH test kits
6. Some soaked samples were saved for agricultural testing

Tumbler used to mix centrifuge tubes during batch experiments

Char Characterization

- Samples of all chars were sent to labs at Colorado State University, North Carolina State University, NIST, and USGS Denver
- A wide range of chemical and physical properties were determined including those shown below

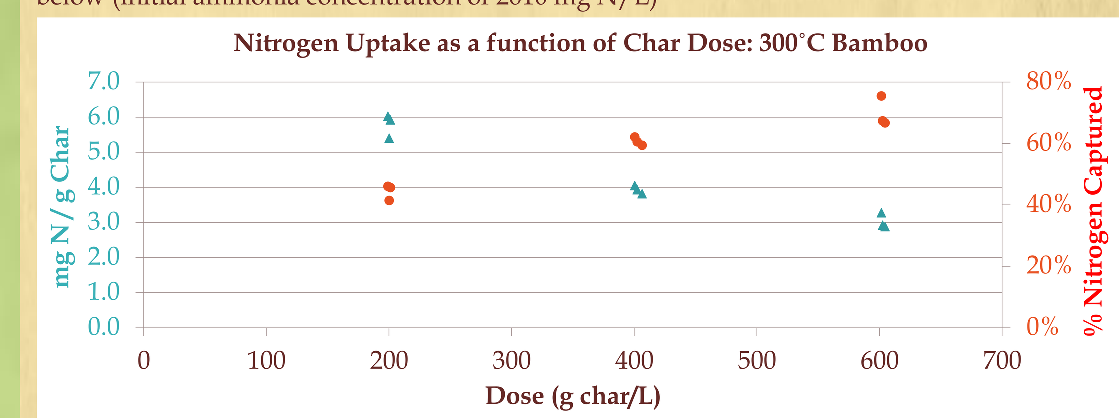
Char Type	Surface area (m^2/g)	% Ash	%C	Surface Groups
300°C Pine	<1	0.67	>85	Hydroxyl group, Aromatic, Carbonyl Groups
900°C Pine	335	1.05		Graphitic
300°C Bamboo	1.5	3.39		
900°C Bamboo	253	2.98	>90	Graphitic
300°C Fecal char	0.6	20.0	58	CH_2, Carbonyl Groups, Aromatic, Aluminum Silicates
900°C Fecal char	126	54.2	55.2	

Nutrient Uptake Results

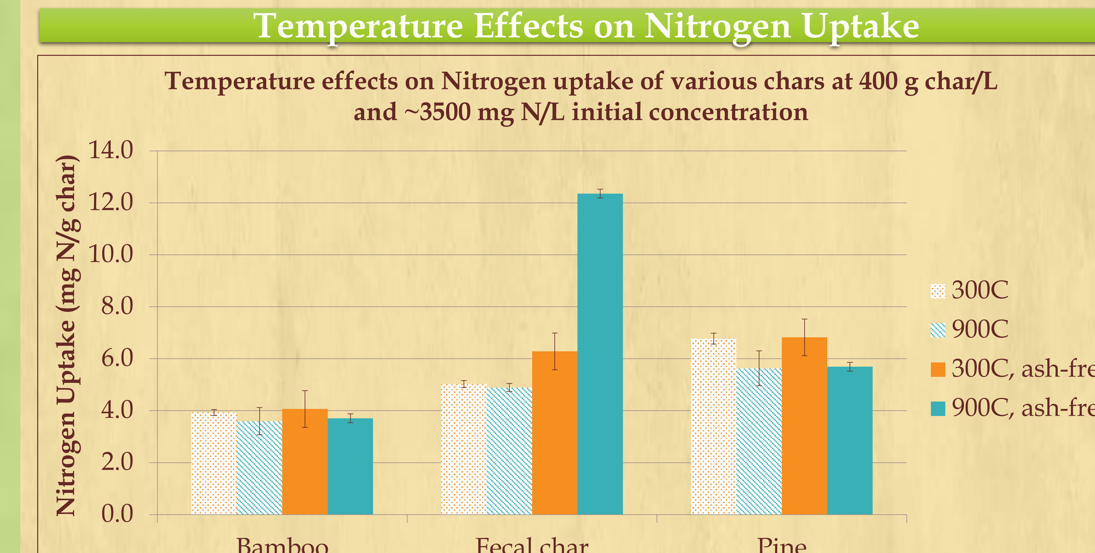
Average uptake of various chars at 400 g/L dose – Uptake varies with different char feedstocks

Char Type	Average Uptake (mg N/g Char)	Standard Deviation	Average P Uptake (mg P/g char)	pH
300°C Bamboo	3.93	0.116	-0.31	6.81
900°C Bamboo	3.60	0.523	0.14	8.92
300°C Pine	6.78	0.210	-	6.58
900°C Pine	5.79	0.670	-	10.1
300°C Fecal char	5.03	0.136	-0.10	9.8
900°C Fecal char	4.89	0.159	0.14	11.2

As char dosage decreases, mg N adsorbed/g C decreases, but % sorbed increases, as shown below (initial ammonia concentration of 2610 mg N/L)

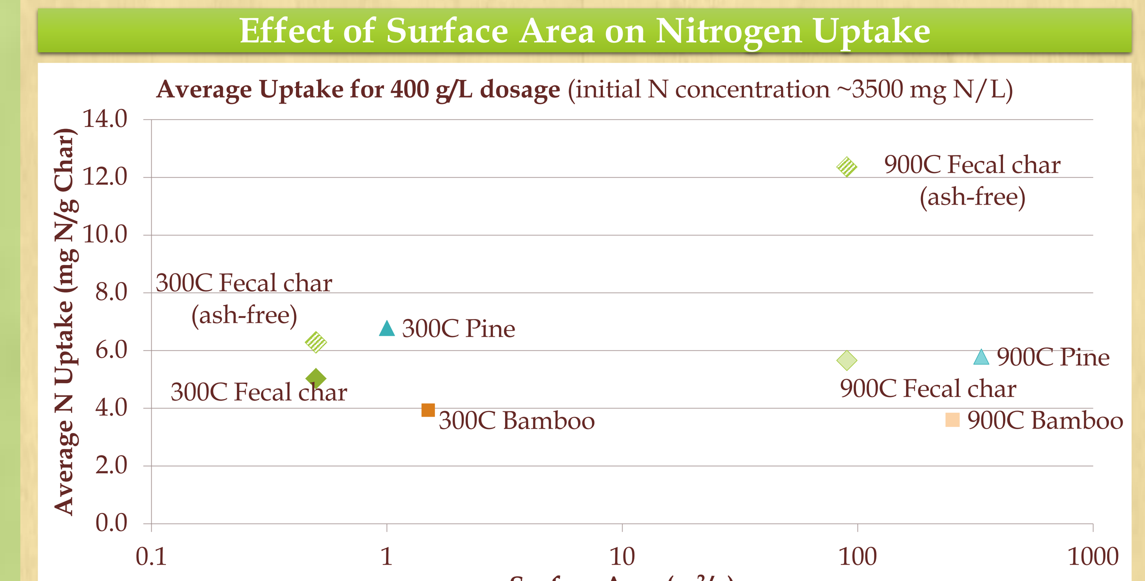


Temperature Effects on Nitrogen Uptake



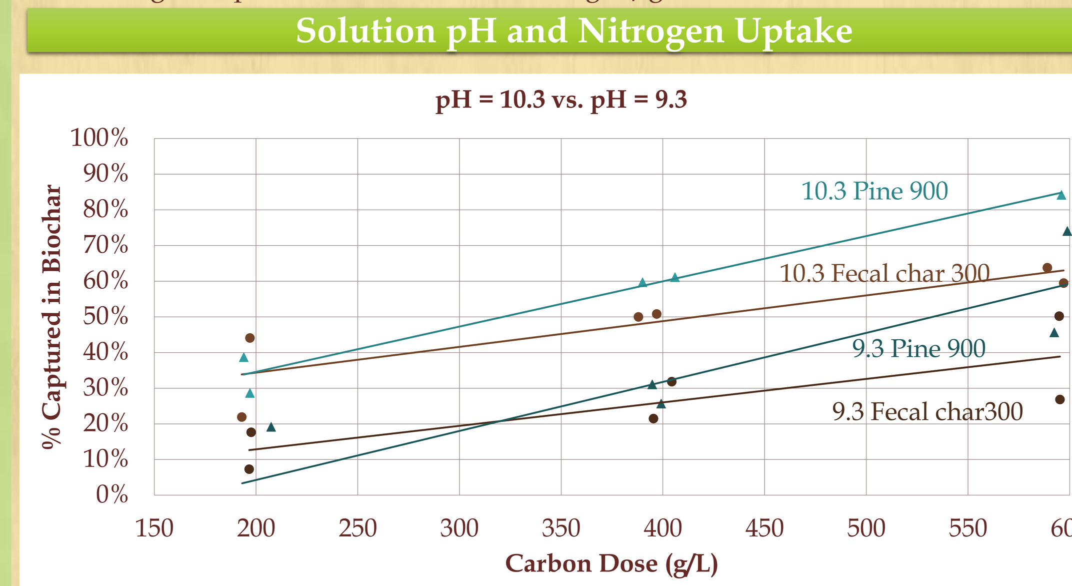
- Temperature has little effect on nitrogen uptake on a per gram of char basis
- On an ash-free basis, 900°C fecal char is the only char that shows considerable mgN/gC increase

Effect of Surface Area on Nitrogen Uptake



- Higher temperature chars have higher surface areas
- On a per gram of char basis, surface area has little to no effect on nitrogen uptake
- On an ash-free basis, higher surface area chars have higher nitrogen uptake per gram of carbon
- Average N uptake is between 3 and 14 mg N/g char

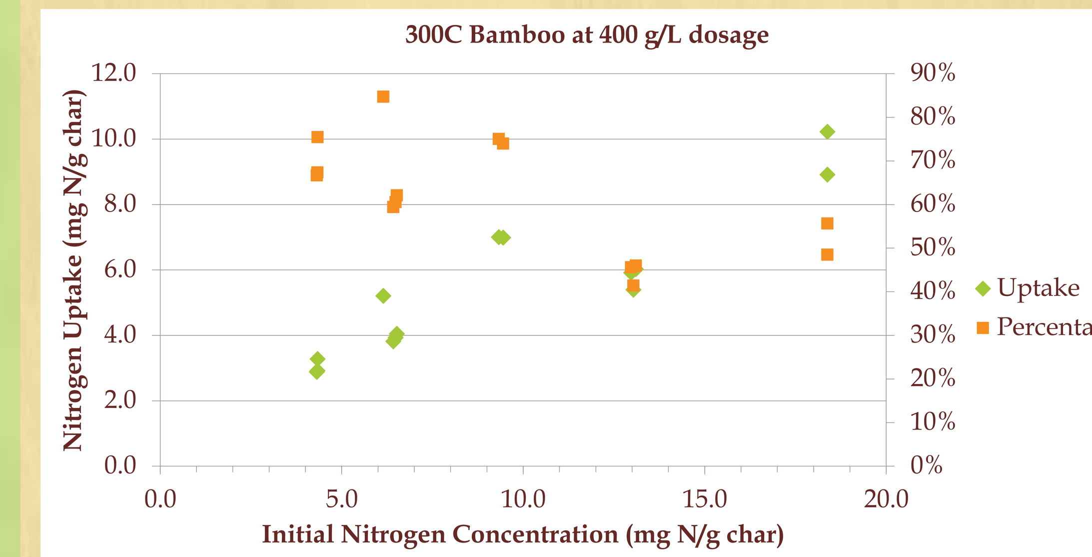
Solution pH and Nitrogen Uptake



- The pKa of NH_3/NH_4^+ is 9.3
- Higher percentage of N is sorbed at pH of 10.3, demonstrating the pH-dependence of ammonia sorption and that NH_3 is preferentially sorbed
- Additionally, chars with higher pH show lower uptake, indicating dependence on acid/base interactions between NH_3 and surface groups – at higher pH, more surface groups become deprotonated

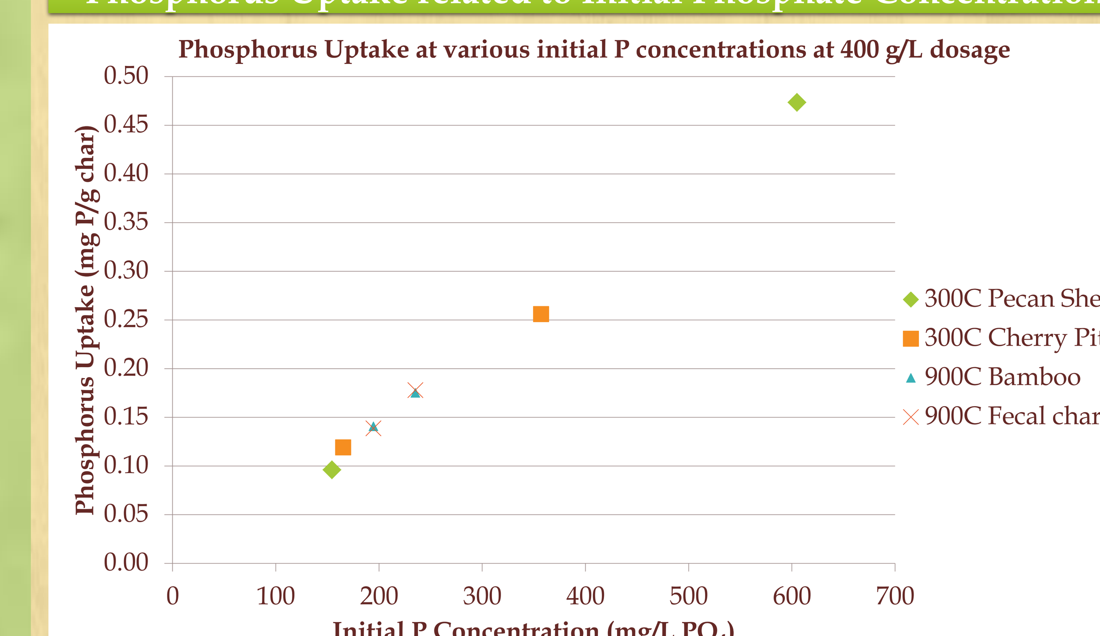
Nutrient Uptake Results

Effect of Initial Ammonia Concentration on Uptake



- As initial nitrogen concentration increases, nitrogen uptake increases as well; however, percentage of nitrogen sorbed by the char decreases
- Synthetic urine recipe showed higher nitrogen concentrations, which would lead to higher uptake rates (not necessarily characteristic of real urine)

Phosphorus Uptake related to Initial Phosphate Concentration



- Chars depicted here lie within a linear trend of increasing uptake with increasing concentration
- Phosphorus uptake per gram of char is very low compared to that of nitrogen and other typically sorbed compounds (organic pollutants) – (i.e.to uptake all phosphorus in 1 person's urine would require on average 1.4 kg 900C bamboo char)
- Some chars, such as 300C bamboo and 300C fecal char resulted in net increase in P in solution – these suggest solubilizing of char or ash phosphorus into solution

Conclusions

- Nitrogen sorption on biochar is influenced by a number of factors, including solution and char **pH** and **concentration of NH_3** in the bulk solution
- One proposed sorption mechanism involves acid/base interactions between NH_3 and carboxyl surface groups – acid washing of char may increase nitrogen uptake[2]
- Biochar made from human fecal matter displays uptake rates comparable to other feedstocks
- Phosphorus recovery via biochar sorption is not a feasible option, and struvite precipitation methods appear to be the preferred method
- Based on an average N uptake of 6 mg N/g char, urine-soaked char can be used as fertilizer for low-N plants at the following rates:

N fertilizer requirement[2]	Char required
20 kg N/he	3.3 metric tons/he
17.8 lbs N/acre	2,970 lbs/acre

Future Work

- Quantify bioavailability of nutrients in urine-soaked chars
- Research on controlled hydrolysis of urine – sequestering the initially lost precipitate formed during hydrolysis and storage
- Investigate possible magnesium additives to enhance phosphorus recovery during ammonia sorption

References

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2. Spokas, Kurt A., Jeff M. Novak, and Rodney T. Venterea. "Biochar's Role as an Alternative N-fertilizer: Ammonia Capture." *Plant Soil* 350 (2011): 35-42. Print.
3. Amstutz, Veronique, Alexandros Katsaounis, Agnieszka Kapalka, Christos Comninellis, and Kai M. Udert, 2012. "Effects of carbonate on the electrolytic removal of ammonia and urea from urine with thermally prepared IrO_2 electrodes" J. Appl. Electrochem 42:787-795

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